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ANSWER BOOK

Summing and difference amplifiers

Electronics · Year 13

AQA 3.13.4.3

17 questions · 52 marks

NAVY EDITION

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SECTION A · Warm-up

A1 Each input drives its own current V/R into the virtual earth, so each input is amplified by its own gain R_f/R_{in} before it joins the total (1). The output is therefore minus the **weighted** sum, with the weights set by the input resistors (1). Adding the voltages first and applying one gain to the lot is the common error, and it only ever gives the right answer when every input resistor happens to be equal. [2]

A2 The inverting input is held at 0 V by the feedback, a virtual earth, so the current through each input resistor is simply that input's voltage divided by its own resistance (1). The op-amp's input resistance is taken as infinite, so no current enters the chip and the whole total leaves through R_f (1). Omitting the second statement is the common error, and without it the derivation does not close. [2]

A3 $V_{out} = (V_+ - V_-) \times R_f/R_1$ (1). Subtract first, then multiply by the gain (1). Amplifying each input separately and subtracting afterwards is the common error: with inputs of a few volts and a gain of a thousand it demands outputs of kilovolts, and the real chip would simply saturate. [2]

A4 The two leads run side by side, so mains wiring induces the **same** interference on both; it is common-mode (1). Identical on both inputs, it appears in both terms of $V_+ - V_-$ and cancels before any gain is applied, while the wanted signal, a genuine difference between the leads, survives at full gain (1). Saying the amplifier 'filters out' the hum is the common error: nothing is filtered, it is subtracted. [2]

A5 The output cannot pass the rails, so it saturates a volt or so inside the rail and stays there, clipping the waveform flat (1). Every design should end by computing the worst-case output and holding it against the rails (1). Writing down the ideal figure, such as -20 V from a ±15 V supply, is the common error, and it is the one examiners mark hardest. [2]

A6 Every gain is a ratio of real resistors, and real resistors carry a tolerance, commonly 5% or 1%, so two 5% resistors can leave a weight almost 10% adrift (1). Each weight must be accurate to better than half a step of the staircase, or the output stops rising in equal steps with the code (1). Assuming the ideal staircase holds however coarse the resistors are is the common error, and it is what drives real converters away from this design. [2]

SECTION B · Standard

B1 Each input sees a virtual earth, so the currents are 0.20/100 kΩ = 2 μA, 0.30/50 kΩ = 6 μA and 0.10/20 kΩ = 5 μA (1). They add at the node to 13 μA, all of which leaves through R_f (1). $V_{out} = -13 \times 10^{-6} \times 100 \times 10^3 = -1.30$ V (1). Dropping the minus sign is the common error here, and it costs a mark every time it appears. [3]

B2 Gains first: 47/47 = 1 and 47/4.7 = 10 (1). $V_{out} = -(1 \times 0.50 + 10 \times (-0.25)) = -(0.50 - 2.50)$ (1) = +2.0 V (1). Watch the double negative: the negative input, amplified ten times and then inverted along with everything else, leaves the output positive. Working the voltages before the gains, or losing one of the two minus signs, are the common errors. [3]

B3 One least significant bit gives 5.0 × 10/80 = 0.625 V, and that is the step (1). The code 0110 is the number 6, so the output magnitude is 6 × 0.625 = 3.75 V (1). Checking by weights: the 4 bit gives 5.0 × 10/20 = 2.50 V and the 2 bit gives 5.0 × 10/40 = 1.25 V, total 3.75 V (1), and the output appears as -3.75 V. If the weighted sum disagrees with count × step, a resistor weight has gone astray; reading the resistor list the wrong way round, so that the MSB gets the 80 kΩ, is the common error. [3]

B4 $V_+ - V_- = 3.4120 - 3.3800 = 32.0$ mV (1). $V_{out} = 3.2 \times 10^{-2} \times 50$ (1) = 1.60 V (1). Amplifying V_+ alone would demand 3.4120 × 50 = 171 V, far beyond any rail; subtracting first is what makes the measurement possible, and doing it the other way round is the common error. [3]

B5 The hum is identical on both inputs, so it appears in both terms of $V_+ - V_-$ and cancels: its contribution is **zero** (1). The difference left is 12 mV (1), so $V_{out} = 1.2 \times 10^{-2} \times 200 = 2.4$ V (1). Amplifying the hum along with the signal and quoting 0.25 × 200 = 50 V of interference is the common error; common-mode means it never reaches the gain stage. [3]

B6 The equation asks for -(3 × 1.0 + 5 × 2.4) = -15 V (1), beyond the -13 V limit, so the output **saturates** at about -13 V and the waveform is clipped (1). For linear working $3 \times 1.0 + 5V_2 \le 13$, so $V_2 \le 2.0$ V (1). Reporting -15 V as the output is the common error: compute the ideal value, then hold it against the rails. [3]

B7 The largest code is 1111, the number 15, so the full-scale output has magnitude 15 × 0.625 = 9.375 V; the summer inverts, so the output itself runs from 0 V down to -9.375 V (1). There are $2^4 = 16$ distinct levels, from 0 to 15 (1). Multiplying 16 by the step and quoting 10.0 V is the common error: n bits give 2^n levels but only $2^n - 1$ steps between them. [2]

SECTION C · Stretch

C1 Seven doublings from the MSB give $R_{LSB} = 10 \times 2^7 = 1280$ kΩ (1). Step = 5.0 × 10/1280 = 3.91×10^{-2} V, that is 39.1 mV (1). Full scale = $(2^8 - 1)$ × step = 255 × 3.91×10^{-2} = 9.96 V in magnitude, the inverting output running from 0 V down to -9.96 V (1). Half a step is 19.5 mV (1), and the MSB contributes the full 5.0 V, so its weight must be right to 19.5/5000 = 0.39% (1). Eight precision resistors are therefore needed, spanning 10 kΩ to 1280 kΩ, a range of 128 to 1, each held to about 0.4% (1). That is why real converters abandon the weighted-resistor design in favour of an R-2R ladder, which needs only two resistor values (1). Two common errors here: multiplying by 256 rather than 255 when finding full scale, and comparing half a step with the **output** rather than with the contribution of the bit whose resistor is in question. [7]

C2 Each gain is R_f/R_{in}, so $R_{in} = R_f$/gain: 100 kΩ, 50 kΩ and 20 kΩ (2). V_{out} = -(1 × 0.10 + 2 × 0.15 + 5 × 0.02) = -(0.10 + 0.30 + 0.10) (1) = -0.50 V (1). Multiplying R_f by the gain instead of dividing is the common error, and it makes the loudest channel the one with the biggest resistor, which is backwards. [4]

C3 $V_+ - V_-$ = 2.5085 - 2.5000 = 8.5 mV (1). Gain = $4.0/(8.5 \times 10^{-3})$ = 471 (1), so R_f = 471 × 1.0 kΩ ≈ 471 kΩ (1). Fed to an inverting amplifier of the same gain, the standing 2.5085 V would demand an output of about 1.2 kV, so the amplifier would sit saturated at a rail and the strain signal would be invisible (1). The standing level is exactly what the subtraction is there to remove; forgetting to subtract before applying the gain is the common error. [4]

C4 The sensor's 0.50 V span must become a 5.0 V span, so its gain is 5.0/0.50 = 10 and R_1 = 100/10 = 10 kΩ (2). At the bottom of the range the sensor alone would give -10 × 1.00 = -10.0 V, so the reference must contribute +10.0 V; with a reference of -1.00 V that needs a gain of 10 as well, giving R_2 = 10 kΩ (1). Check: at 1.00 V in, V_{out} = -(10 × 1.00 + 10 × (-1.00)) = -0.0 V (1). At 1.50 V in, V_{out} = -(10 × 1.50 - 10) = -5.0 V (1), inside the rails. The common error is to treat the reference channel as a fixed voltage added at the output rather than as another weighted input; it has its own gain R_f/R_2 like every other channel. [5]